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Original Communication

The use of infrared aided photography in identification of sites of bruises after evidence of the bruise is absent to the naked eye

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ABSTRACT

The purpose of the study was to determine whether Infrared imaging could play a role in the detection of previous blunt force injury after resolution of skin changes were no longer visible to the human eye. Investigations were performed using an adapted digital camera and the same standard Nikon camera body to photograph the bruises of ten volunteer adult subjects. The same lens was fitted to each camera body and each bruise was photographed until it was no longer possible to identify it with the naked eye.

The results of photographing subjects over 6 months demonstrated that the median time the bruises persisted in both groups was approximately between 18 and 19 days. There was no statistically significant difference between groups of bruises photographed with both the infrared digital camera that had been adapted to capture only infrared light, and with the standard camera which had the same lens fitted to it.

The two groups of photographs of bruises imaged at the same time with the two cameras were not significantly different with regard to what skin changes could be detected. The use of the near infrared spectrum, with wavelengths that are longer than the human eye can detect, did not reveal significant evidence of bruising after it had faded from view to both the human eye and to a standard camera.

1. Introduction

Bruises are often presented as crucial visual evidence of injuries in forensic medicine and their presence or otherwise may be recorded in various ways using both film and digital photographic images. Determination of the age of an individual bruise on both adults[1] and children[2–6] has been extensively investigated over many years and since the development of professional digital cameras there has been increasing interest in performing photography outside the range of the electromagnetic spectrum that is visible to the human eye.[7]

Digital cameras currently provide an easy and quick method of recording images and various types of cameras have been used to do this. On occasions even mobile phones with inbuilt cameras have been used and most of these devices record the time and date that the bruises have been photographed.

In the 1990's Williams[8] and others employed infrared (IR) film-based technology to reveal structures beneath the skin. This has also been used in vascular studies to distinguish between oxygenated blood (which reflects IR well) and venous blood (which absorbs IR heavily).

This study attempted to determine if, as a bruise fades and is no longer visible to the human eye, IR digital photography is able to make the injury evident again. It has been shown that IR may penetrate the superficial layers of the epidermis (up to approximately 3 mm)[9] which present the theoretical possibility of visualising early bruising through the ability to detect the pooling of subcutaneous blood.[7]

It was against this background of using the wavelength of light and the ability of a camera to record this in the skin that the potential of digital cameras and IR light was considered. Vogeley[10] discussed that the IR spectrum, which consists of wavelengths that are longer than the human eye can detect (>700 nm), has the deepest penetration of skin. This gives the prospect that electromagnetic

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Table 1
Mean, standard error, percentile estimates and confidence intervals for the survival times of bruises. The table presents the Qth percentiles for the dataset for $Q = 25$, 50 and 75. For example, a Q of 50 corresponds to the median of the dataset i.e., the point beyond which approximately 0.50 of bruises could not be detected. Estimated 95% lower and upper fiducial limits for the median estimate are also given. For these data, the estimated median was 18.5 days with 95% confidence limits estimated to range from 13 to 21 days. The mean of the dataset with its concomitant standard error is also provided although it is the median estimates that are usually more relevant.

Quartile Estimates	95% Confidence interval		
Percent	Estimate	Lower	Upper
75	21.0000	18.0000	37.0000
50	18.5000	13.0000	21.0000
25	13.0000	8.0000	19.0000
Mean	Standard Error		
18.5000	2.5044		

radiation (near-IR) in the wavelength between visible red light and radio waves may detect the later stages of healing of a bruise.

If it was feasible to use the IR part of the electromagnetic spectrum to detect changes in the later stage of bruising, then this might capture evidence for presentation to a court of late reporting of injuries; in particular those associated with child abuse, domestic violence and allegations of assault against police officers.

This study attempted to determine as a bruise fades and is no longer visible to the human eye, if IR digital photography is able to detect the injury. This was performed by using IR light to obtain photographic evidence of bruises on the limbs of 10 healthy adult volunteers. Subsequently, computer software was employed to view the RAW data from the camera and create an image.

The study also considers the ability of digital cameras to provide strong evidence, in relation to the time and place a photograph was taken, to ensure evidential integrity in the context of image manipulation.

2. Methods

Two digital camera bodies were used with one Nikon macro lens which was switched between the bodies when needed. No flash or tripod was used. The RAW images captured were processed on a computer using *Adobe Photoshop* CS3 and a copy of the original RAW data was stored on an external hard drive. All findings were confirmed using Nikon's software Capture NX.

2.1. Camera bodies

Two identical Nikon camera bodies were used in the study. There are some technical needs required for Infrared digital photography and Busch checked many of the available digital SLR's to see how well each one tested rendered IR. The Nikon D70's 'filters out much of the infrared illumination, but still lets enough through to allow wonderful IR images.'[11] The correct time and date were set on the two camera bodies by the investigator. The aperture priority command dial was set on both of the cameras and all images were taken with an International Organisation for Standardisation (ISO) of 400.

2.2. Lens

The bodies of the two cameras both required the attachment of a suitable lens. The Nikon Micro Nikkor 105-mm f/2.8 lens has been widely used to photograph bruises[3,7] and this single lens was used on both camera bodies. No attached filter of any kind such as UV, skylight or neutral density was used to take any of the images of the bruises. The lens provided an adequate camera/subject working distance at the scale being used (1:4).

2.3. Light

Natural sunlight was used throughout the study to record the images.

2.4. Images

When a picture was taken with the camera it was assigned a number by the internal computer of the camera (e.g., DSC_0001 and then DSC_0002). A large number of pictures was taken over many months, therefore the FILE NO. SEQ. menu option[12] was set to allow the camera to continue the sequencing after a memory card had been reformatted.

2.5. Cards

Two compact flash (CF) memory cards were used and each was a different brand. A SanDisk ultra 11,254 MB one was used in the standard D70 body and a Fujifilm card on in the adapted camera body. The two brands made it easy to distinguish between them when they were removed from the cameras. The same cards were always used in the same camera body and care was taken that the sequence of numbers given by each of the cameras was different.

The card was reformatted and placed back in the cameras with all the images for that subject on that day deleted once the data had been removed from the card. The images were then placed on both the hard drive of the computer and stored on a separate external hard drive.

2.6. Edit

RAW images were processed on a computer using *Photoshop CS3* and Nikon Capture NX (version 1.3).

2.7. Statistical methods

The method of analysis used was the technique of survival biometrics. This approach is adopted widely by medical and actuarial researchers who are concerned with the variable time before an event occurs. In trials involving a new treatment for cancer, for example, this may be the survival time to death from when treatment was first administered. In this current pilot trial, survival time was taken as the time from when a bruise occurred to when it was no longer visible by the IR method of digital photography under investigation. The particular method used was to estimate the underlying survivor function for the process $S(t)$ by the use of Kaplan–Meier curves.[13]

The Kaplan–Meier estimate of the survivor function $\widehat{S}(t)$ is:

$$\widehat{S}(t) = \Pi_{j=1}^{k} \frac{n_j - d_j}{n_j} \quad \text{for } t_{(k)} \le t < t_{(k+1)}$$

assuming the ordered times to invisibility (and hence the ordered interval start times) are denoted, $t_{(1)}$, $t_{(2)}$, $t_{(3)}\ldots,t_{(r)}$ with $t_{(0)} = 0$ and there are $j = 1,\ldots, r$ separate times when bruises were no longer visible.

- n_j = the number of bruises visible just before time $t_{(j)}$,
- d_j = the number of bruises becoming invisible at time $t_{(j)}$,
- c_j = the number of individuals censored in $[t_{(j)}, t_{(j+1)}]$.
- $n_j = n_{j-1} - d_{j-1} - c_{j-1}$
- $\widehat{S}(t) = 1$ for $t < t_{(1)}$ and $\widehat{S}(t) = 0$ for $t > t_{(r)}$ if and only if the last observation is a definite lack of visibility at that time.

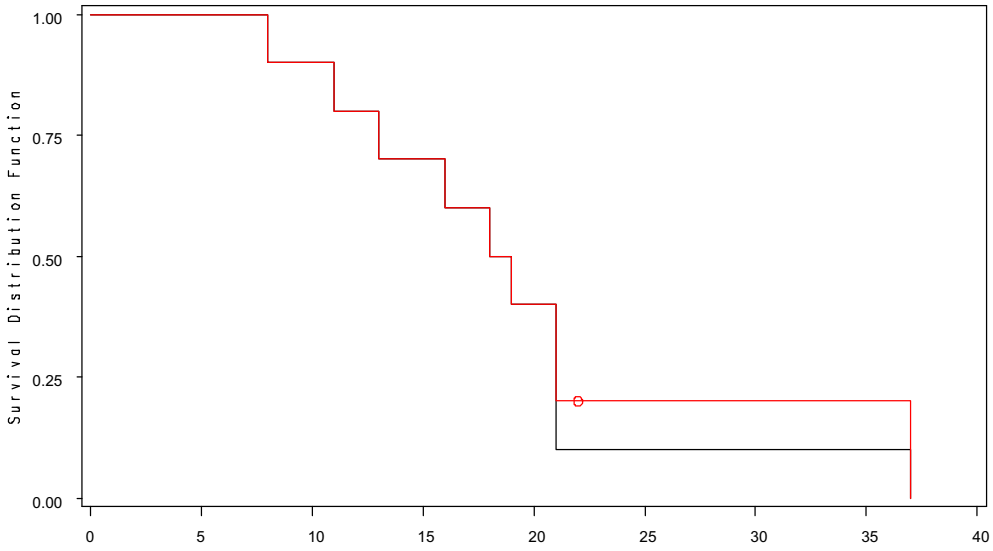

Fig. 1. Kaplan–Meier estimator graph for Estimated Survival Times for Bruises Identified by Human Eye and by IR. This figure estimates the survival function from life-time data comparing the standard camera versus the IR adapted camera. Testing the null hypothesis of no difference using the Wilcoxon Test (NS) using a level of significance of $\alpha = 0.05$, we reject H_0 if $z < -1.96$ or if $z > 1.96$. With the value of $z = 0.8795$ we can conclude that there is no significant difference between the two comparators in the test.

For photographic and other methods under investigation, the Kaplan–Meier curves were compared using Wilcoxon's test and a chi-squared distribution with one degree of freedom to identify the crucial point for rejection of the null hypothesis that the survival curves did not differ significantly.

3. Results

The Kaplan–Meier estimator graph shown in Fig. 1 estimates the survival function from life-time data obtained from the two cameras from when a bruise occurred to when it was no longer visible using either method Table 1. Due to the type of study and the methods used in other similar medical studies, the analysis has been compiled using the Kaplan–Meier Estimator and the Wilcoxon Test of Significance.

The graph demonstrates how the two methods produced almost identical results for most sampling points up until time = 21. Although the nonparametric test used does highlight a degree of variance between the results, due to the high level of covariance for the Wilcoxon statistics (696.057 & −696.057), this indicates that there is no significant difference between the two methods. Further, testing the null hypothesis of no difference using the Wilcoxon Test (NS) using a level of significance of $\alpha = 0.05$, we reject H_0 if $z < -1.96$ or if $z > 1.96$. With the value of $z = 0.8795$ we can conclude that there is no significant difference between the two comparators in the test.

Considering all of the analysis using the stated methods, it is clear that there is a strong degree of correlation between the two camera methods that were used. Having tested the null hypothesis using three different statistical tests and the null hypothesis rejected each time, the results of the study are conclusive that using different cameras to study the bruising made no significant difference to the outcome.

It was only possible with one of the bruises (subject 7) to demonstrate a bruise by IR which was no longer visible to either the human eye or the standard camera (see Fig. 2). A landmark mole on the arm of the subject is shown with an arrow to allow comparison.

4. Discussion

The aim of the study was to determine if, with bruises as the photographic subject, it was possible to detect late reporting of bruising using a digital camera adapted for only near IR and so to establish if IR studies can provide information which could not be obtained in any other way.

IR is part of the spectrum just below the red end of visible sunlight, which was originally discovered by William Herschel in 1800. Visible light is just one part of the full range of energy that nature produces and IR is electromagnetic radiation in the wavelength range between visible red light and radio waves; there is said to be almost complete absorption of it in the lower layer of the Earth's atmosphere, primarily by water vapour.

The investigator initially established that when using the adapted camera during daylight, there was sufficient energy to produce an IR image. It was simple with a camera such as the D70 to look at the monitor on the back of the camera and to see immediately that an image had been taken. There was always enough light with a wavelength close to visible light – the so-called near-IR – to penetrate the Earth's surface and to reach the skin of the subject and to allow an image to be recorded by the sensor on the camera.

Technicians from Advanced Cameras in Norfolk performed the IR adaptation by adding a filter internally into the camera body; therefore no filter was necessary on the front of the lens. The result of having the barrier to all but IR light inside the camera, rather than outside on the front of the lens, was that changing the lens, composing and focusing was fast and easy.

The diffraction effect on IR photography noted by Nieuwenhuis[14] in an examination of the photography of bruises using film at apertures smaller than f/11 was not seen in this study. The reason why this did not happen was unclear. It may have been because the camera was digital or more likely because such small apertures were not used.

Digital IR photography has been reported in a number of studies as a useful method of recording bruises. This has not just been in forensic medicine, such as with suspected child abuse,[15] but also in commerce with products as wide-ranging as apples with bruises[16], chicken products[17], and Pacific pink salmon (*Oncorhynchus gorbuscha*) when bruising was detected by visible and short-wavelength near-IR (SW-NIR) spectroscopy (600–1100 nm).[18] Both bruised and non-bruised regions of the salmon were measured in a non-invasive way through the skin and scale using digital images. In the study of chicken carcasses, bruises were one of six major defects that caused this product to be removed from the processing line and they were detected by near-infrared reflected light.

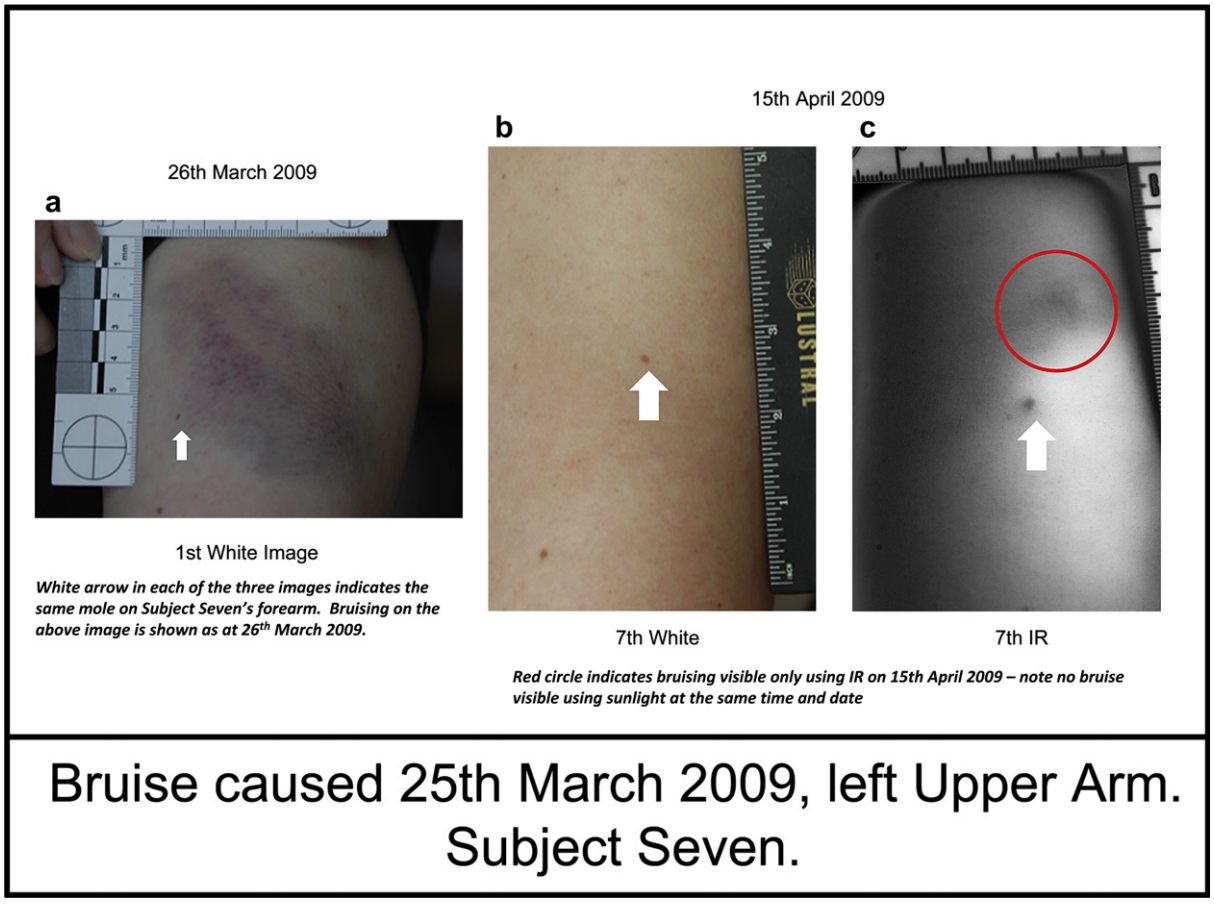

Fig. 2. Photographic images of one bruise over time from same subject (subject 7). This figure demonstrates photographic images of one particular bruise on subject 7. This bruise was sustained on 25th March 2009 and was first photographed in sunlight 18 h later using the standard D70 camera body with the Nikon Micro Nikkor 105-mm f/2.8 lens attached (a). On 15th April 2009 (day 21) this bruise appeared to have faded to both the investigator and the subject as viewed using the naked eye. It was photographed that day in sunlight with the standard D70 using the same lens (b). The IR adapted D70 with the same lens attached detected it that day as demonstrated in c. The red circle on c indicates bruising visible only using IR. The arrow on each photograph indicates a mole on the skin to allow orientation of the original bruise in relation to the IR detected bruise.

In this pilot study it was not possible to prove statistically that it was possible to detect bruises using IR after they have faded from view by the eye. However in one subject (subject 7) the presence of the bruise was detected using IR (with the adapted D70) when both the subject and the investigator had agreed, before an image had been taken, that the bruise was no longer visible.

Light is the part of the electromagnetic spectrum that we can distinguish with our eyes.[19] All IR photography of the digital kind captures images in what is called the near-infrared (NIR) range; that is the IR light that is just beyond the range of human vision. This form of photography does not capture far IR or heat radiation but relies on a subject that reflects substantial amounts of IR.

A variety of light sources has been used in other studies. The high energy output of electronic flash has also proved an excellent light source for both reflected IR and ultraviolet image capture. Equipment such as the professional Bowen Esprit II 125 flash unit with an uncoated flash tube (for its high ultraviolet and IR output) used by Tetley[7] was considered impractical for the forensic doctor. The most reliable light source, and the one used throughout, was sunlight. A battery powered Nikon flash SB-800 with a filter fitted which excluded all but IR light from the flash head was used initially but this was found to be impractical. The actual power of the flash showed unexpected power variations. Also the flash needed to be set manually as the various automatic controls of the camera, the lens and the flash unit had only ever been intended by Nikon for standard digital photography.

The photography occurred on an opportunistic way over 6 months and every bruise was photographed whenever possible. It was not feasible to have the same time frame of image collection for every subject because of the changing work shifts of the volunteers. In this study after a trial with the adapted flash it was found that the most consistent source of light (visible and IR) was sunlight. All the photographs of the bruises were taken using sunlight during the months of November 2008 to April 2009 between 10 am and late afternoon. There was some inevitable variation of the IR depending on the amount of sun on a particular day and the positioning of the sun.

It remains unclear why only the bruise in Subject 7 could be revealed after it had faded from view (see Fig. 2). One possibility is that with the bright sunlight available at that time in spring there was more IR present.

The two D70 cameras used in the study had a time and date record which needed to be set by the user[11]. In such examples of collecting forensic evidence it is important to provide sound evidence, particularly in relation to the time an image was taken.

In the study the most reliable method used to record the time, date and place that images were taken was found to be to write this information down on paper first and then photograph this as the initial image and then to keep it with the records of the images of the bruises.

In forensic work, with the need for a watertight audit trail, the investigator might wish to consider such cameras as the Nikon D90, D200, D300, D700 and D3/x digital SLR cameras, to which may be

attached the Nikon GP-1 GPS Module. This will record the exact location of the camera when a picture is taken so that latitude, longitude, altitude and time are automatically recorded as geotags in the image data (EXIF). There has been at least one criminal case known to the investigator in which a trial was halted because the date that a crucial photograph was shown by the defence to be inconsistent with police statements.

The other consideration in the study was regarding preserving the evidential integrity in the context of image manipulation. This is clearly of great importance if any images are provided as evidence for a Court. In this study the original RAW image was always preserved and a safe copy kept on an external hard drive. The application of *Photoshop* to the data did show, particularly in Subject 7, the presence of a known bruise when human eye and the standard D70 could no longer detect it. However *Photoshop* was not manipulating the image to enable the investigator to show anything which was not present below the surface of the skin.

There are a number of software programs which facilitate editing of digital images and *Photoshop* is one of the most familiar of these methods. Adobe *Photoshop*™ CS3 was used to work on the RAW images of the bruises on a computer. The RAW IR images were also viewed again using Nikon Capture NX (version 1.3). This different form of software gave a second view and would confirm the findings which *Photoshop* had revealed.

One part of what might be called this 'second opinion' was the IPTC Metadata[20] of Nikon NX. This software could also process the image of a bruise and would not only get the same visual result as its rival *Photoshop* but it was also used as it provided a permanent record of the time the bruise had been photographed and also all the settings on the camera.

Two RAW images of bruises (one with the IR camera and one with the standard one) were opened in camera RAW with *Photoshop CS3*. The easiest and most helpful method to initially view the evidence was to apply the Auto settings of *Photoshop*. With this method the bruise was slightly more evident on the investigator's monitor.

The appearance of the bruise was made more obvious by increasing the contrast and decreasing the saturation using camera RAW. It was also possible to open the image using the auto settings in Camera RAW and then increasing contrast using Curves and then reducing the saturation using the hue/saturation adjustment. In either case the bruise only became slightly better defined and neither method seemed to be better than the other.

Whatever precise methods employing computerised software were used on the original data the original RAW image was always saved so that if any of the results were challenged, as in a Court of Law, then the way this may be undertaken could be demonstrated.

If required, there is also Image Authentication Software designed for use with specific Nikon digital SLRs, which allows the authentication of an image captured by the camera. This allows one to determine whether or not any image has been altered since capture.

5. Conclusion

The use of certain digital cameras now enables the user to provide a watertight method of recording the time and date that an image has been taken. It is also possible to prove that data has not been manipulated. The use of IR light alone to record an image of a bruise may have the ability to demonstrate the presence of a bruise after the injury is no longer visible to the human eye but this will require further studies to determine optimal light sources.

Conflict of interest/funding

All authors declare there are no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three (3) years of beginning the work submitted that could inappropriately influence (bias) their work.

Ethical approval

This research was performed in accordance with research governance and ethical regulations which were adhered to at all times. Ethical approval was obtained from the University of Ulster, School of Biomedical Ethics Filter Committee. All information was anonymised Every effort was made to ensure that personal identification could not take place by any reader.

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